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Object Oriented Reconstruction and Particle Identification in the ATLAS Calorimeter

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Abstract

The reconstruction and subsequent particle identification is a challenge in a complex and a high luminosity environment such as those expected in the ATLAS detector at the LHC. The ATLAS software has chosen the object oriented paradigm and has recently migrated much of its software components developed earlier using procedural programming languages. The new software, which emphasizes on the separation between algorithms and data objects, has been successfully integrated in the broader ATLAS framework. We will present a status report of the reconstruction software summarizing the experiences gained in the migration of several software components. We will examine some of the components of the calorimeter software design, which include simulation of real-time detector effects and online environment, and strategies deployed for identification of particles.

Keywords: calorimeter, reconstruction

1 Introduction

The high instantaneous luminosity environment of the LHC (10^{34} cm^{-2} s^{-1}) poses a unique challenge in the ability to accurately reconstruct and identify particles within the ATLAS detector. The large number of detector channels and increased occupancy due to pile-up effects from multiple bunch crossings requires a careful design of the reconstruction software. The transition from the procedural programming language (fortran) based analysis program "Atrecon" to the object oriented approach of Athena using C++ has been made within ATLAS.

The object oriented approach to the ATLAS calorimeter reconstruction software development works within a framework which emphasizes the separation of algorithms and data objects. The method by which data objects are handled is particularly important because of the large event sizes expected at the LHC, of which the calorimetry represents a sizeable fraction.

2 The Gaudi and Athena Framework

Athena is the ATLAS common software control framework based upon the Gaudi architecture [1]. Athena represents a concrete implementation of this underlying architecture and is the sum of this kernel framework together with ATLAS specific enhancements which include the event data model and event generator framework. The Athena framework follows a blackboard architecture where algorithms produce data objects that are posted in a blackboard (transient data store) which are consumed by other algorithms. The framework provides several services such as dynamically loading algorithms and their properties, conversion services to persistify data objects produced by algorithms, and services to post data objects into the blackboard.

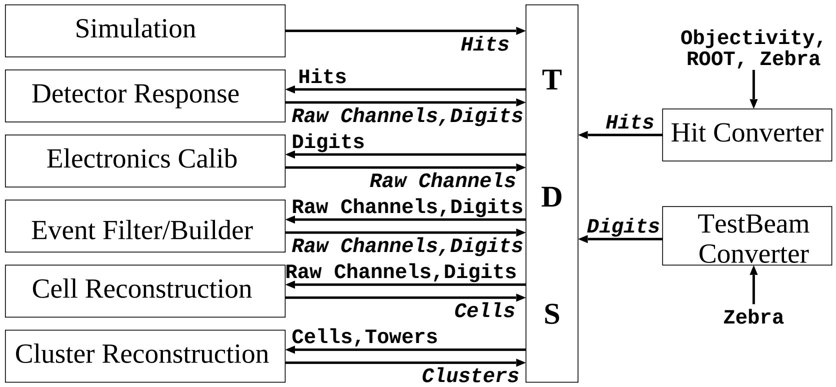

Figure 1: Schematic of the ATLAS software interfaces to data objects within the Transient Data Store (TDS).

Within the Athena framework data can be read in from several persistent sources such as Zebra [2], ROOT [3], and Objectivity [4] for both Monte Carlo and testbeam data. The ATLAS software environment is based upon the concept of Packages which function within the Athena framework and act as both a management and software configuration tool [5].

3 Components of ATLAS Calorimeter Reconstruction Design

The ATLAS calorimeter consists of electromagnetic (EM) and hadronic liquid Argon (LAr) and hadronic Tile calorimeters. The EM calorimetry is a lead-LAr detector with accordion shaped Kapton electrodes and lead absorber plates providing coverage over the barrel ($|\eta| < 1.475$) and end-cap ($1.375 < |\eta| < 3.2$) regions. The hadronic LAr calorimetry utilize differing detector designs and covers the end-cap and forward regions for η values of $\sim 1.5 < |\eta| < 4.9$. The hadronic Tile calorimeter is a sampling calorimeter using iron as the absorber and scintillating tiles as active material with coverage provided over the barrel region ($|\eta| < 1.7$). The LAr and Tile calorimeters represent approximately 200000 and 6200 read-out channels, respectively. A presampler detector is instrumented within the pseudorapidity range $|\eta| < 1.8$ and is used to correct for the energy lost in material (inner detector, cryostats, coil) upstream of the calorimeter.

Several software packages have been established with specific functionalities in order to handle the processing of Geant3 (G3) and Geant4 (G4) calorimeter detector hits to final reconstructed objects. Figure 1 presents a schematic of the interfaces between the ATLAS software and the data objects within the transient data store (TDS), along with the various methods by which the interactions occur.

The hits produced by G3/G4 describe the visible energy deposited in any given calorimeter cell. Digitization algorithms use these hits to emulate the front-end board electronics along with the effects of thermal noise, pulse shape, cross talk, and coherent noise. The Level-1 trigger is used to identify, for each event, regions of the detector containing interesting features such as high-p_T EM clusters, jets, and muons. Upon a Level-1 trigger accept, the read-out driver collects the digitization from the front-end board and converts the 40 MHz sampled analog waveform to energy, peaking time and a quality using the Optimal Filtering techniques [6]. During the Level-2 trigger stage, full-precision information combined from the inner tracking detectors, calorimeters, and muon detectors, are used to provide better particle identification and higher measurement precision than are possible in the Level-1 trigger. If an event is accepted by the Level-2 trigger, all data for that event are sent to the Level-3 trigger, which is capable of full event reconstruction and where the final event selection and classification of events, to be recorded for offline analysis, is performed. Athena is currently under evaluation for use as the Level-3 trigger software.

From the calorimeter information the reconstruction of calorimeter cell, tower and cluster objects is performed. A common interface has been established such that downstream particle algorithms do not have knowledge of the specific calorimeter from which the reconstructed object came. The adoption of a base class common to the LAr and Tile calorimeters has the advantage of reducing the dependency of the calorimeter object upon a specific calorimeter. Sub-detector specific information, including any relevant back pointers to raw detector data objects, is maintained in a sub-class. Towers and clusters maintain back pointers to the cells that created them. Traceback to the calorimeter sampling from which a cell came is also made possible through the common interface.

The common base class also allows for the reconstruction of combined LAr/Tile towers. The reconstruction of calorimeter towers proceeds through the division of each calorimeter into an (η, ϕ) grid. Cells from each calorimeter are added together according to the specified (η, ϕ) granularity: typically 0.025×0.025 for EM showers and 0.1×0.1 for hadronic showers. A sliding window algorithm, with a 5×5 cell window, is applied on the tower grid to find positions of cluster maxima, around which the cells are summed in a specific region. Such clustering mechanism limit the number of fake clusters to less than 2% for $E_T > 2$ GeV at high luminosity after noise and pile-up treatment. Implementation of other cluster algorithms, including neural networks for example, are being investigated.

4 Particle Identification and Analysis

Several packages exist to perform various levels of particle identification and analysis. These packages include algorithms to select and identify electron/photon, tau, and jet objects within each event. Further algorithms are included to perform other analyses such as the reconstruction of missing E_T.

4.1 Electron/Photon Reconstruction

The electron/photon (egamma) reconstruction algorithm begins by dynamically loading various needed sub-algorithms and loops over the reconstructed clusters using the calorimeter cluster object as the seed. The sub-algorithms perform specific tasks such as determining shower characteristics (shape, isolation, leakage, etc.) or finding a matching track, and possibly application of corrections and selection criteria. For the reconstructed egamma candidates the shower properties are retained along with pointers to the cluster and matching track. Very good agreement is observed between Athena and Atrecon at both the digits and cluster level for the egamma reconstruction. Figure 2 demonstrates the reconstructed Higgs boson invariant mass with Athena where $H \to \gamma\gamma$.

4.2 Jet Reconstruction

Included within the ATLAS software is a package to reconstruct hadronic jets with the help of implemented jet reconstruction algorithms. The aim of the present design is to make jet reconstruction possible using particles, cells, towers or clusters in the calorimeters. These elements are subsequently treated as an abstraction called protojets, and can be used to reconstruct jets. Once the input object is converted to a protojet any of the reconstruction algorithms to find jets can be called. To date the K_t and seedless cone algorithms have been implemented. Simple algorithms have also been constructed which apply jet energy corrections, access to sampling information, as well as access to lists of cells found within jets. Clustering of the protojets is also possible as a pre-processing stage before jet finding is initiated and is typically run when working directly with calorimeter towers.

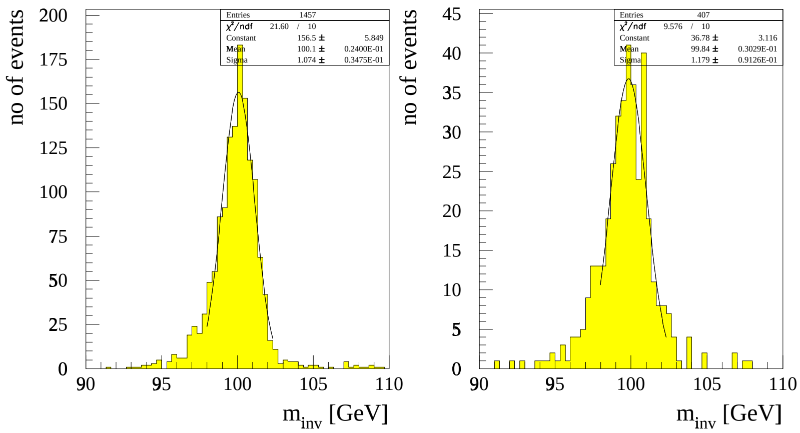

Figure 2: Reconstructed Higgs boson mass from Athena for $H \rightarrow \gamma\gamma$, $M_H = 100$ GeV, for low luminosity (left) and high luminosity (right) at the LHC.

4.3 Missing E_T Reconstruction

Within the Athena framework the reconstruction of missing E_T proceeds by looping over all calorimeter cells, including those of the forward calorimeter. For each cell the deposited transverse energy E_T along with its x and y components is used to compute the global missing E_T through the assumption of balanced total transverse momentum within the event. Work is in progress to expand the algorithms employed so as to also handle reconstructed objects such as isolated e, γ, jets, clusters not accepted as jets, and muons. Methods to deal with low energy cells found both inside and outside of clusters are also being investigated due to the impact of such cells upon the missing E_T resolution.

4.4 Particle Identification

The particle identification object is foreseen to later include an implementation of a kinematic interface along with the pointers to the particle candidate object. Pointers to an overall probability object is also planned. The probability object may contain probabilities, hypotheses, and flags and would also define multiplicative and additive operators to merge the probabilities. A prototype implementation is underway to test the proposed ideas. The aim is to eventually extend this method as a general strategy for particle identification for egamma objects along with tau, jets, b-mesons, muons and other particles. The candidates should provide access to the information required for final classification of the particle.

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